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A STUDY OF PLANING CATAMARAN HULL AND TUNNEL INTERACTIONS

T. Jeff Sherman, et al

Michigan University

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T. Jeff Sherman
Peter A. Fisher
Richard B. Couch

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
A high speed, low displacement set of catamaran hulls has been model tested with various hull separations and tunnel heights. Symmetric, axisymmetric and unsymmetric hull forms have been tested and compared in terms of resistance to determine the interaction effects of the sponsons. A computer program for the prediction of power for prismatic planing boats has been modified to include catamarans.

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COLLEGE OF ENGINEERING
Department of Naval Architecture and Marine Engineering
Ship Hydrodynamics Laboratory

A STUDY OF PLANING CATAMARAN HULL AND TUNNEL INTERACTIONS

Final Report
by

T. Jeff Sherman
Peter Fisher

Project Director
R. B. Couch

DRDA Project No. 011073
under contract with:
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Department of the Navy
Office of Naval Research
Arlington, Virginia 22217

February 1975

Abstract

Little doubt exists that the catamaran hull form offers a considerable operational advantage over the conventional monohedron hull form under certain specified constraints. There has been a renewed interest in the application of the catamaran for high speed , limited displacement service. However, in many instances, model tests have indicated conflicting results in the evaluation of resistance data.

Three pairs of symmetric, assymmetric, and unsymmetric hulls have been tested at the Ship Hydrodynamics Laboratory of The University of Michigan to determine the effects of hull separation, hull form and tunnel height. Data has been presented comparatively in each case and expanded to a full scale corresponding to a displacement of 100,000 pounds.

NOMENCLATURE*

A_P	:	Projected planing-bottom area, excluding area of external spray strip, sq. ft.
B_P	:	Beam on breadth over chines, excluding external spray strip, ft.
B_{PA}	:	Mean breadth over chines: A_P/L_P, ft.
B_{PT}	:	Breadth over chines at transom, excluding external spray strip, ft.
B_{PX}	:	Maximum breadth over chines, excluding external spray strip, ft.
BL	:	Base Line
b	:	Breadth over spray strips at longitudinal center of gravity, ft.
CL	:	Center Line
CG	:	Center of gravity
C_T	:	Total resistance coefficient
C_R	:	Residuary resistance coefficient
h	:	Finite water depth, ft.
F_N	:	Froude number based on length = $V/\sqrt{GL}$
F_NL	:	Froude number based on depth = $V/\sqrt{GH}$
F_∇	:	Froude number based on volume = $V/\sqrt{GD^{1/3}}$
[illegible]	:	Acceleration of gravity, ft/sec^2
L_{AV}	:	Average wetted length, ft.
LCG	:	Longitudinal center of gravity
L_P	:	Projected chine length, ft.
L/D	:	Lift-drag ratio
P_E	:	Effective horsepower
R_{T_M}	:	Total model resistance, lb f

R_{TS}	:	Total ship resistance, lbf
R_R/Δ	:	Residuary resistance - displacement ratio
R_{TS}/Δ	:	Total ship resistance - displacement ratio
$Rise/\nabla^{1/3}$	:	CG rise coefficient
S	:	Wetted surface, sq. ft.
$S/\nabla^{2/3}$	:	Wetted surface coefficient
V_W	:	Velocity of wave propagation, ft/sec.
V_K	:	Velocity in knots
V_M	:	Velocity of the model, ft/sec.
$V/\sqrt{L}$	:	Speed-length ratio
α	:	Angle of attack at after portion of planing bottom, degrees
λ	:	Scale ratio, ship to model
λ_W	:	Wave length, ft.
β	:	Deadrise angle of planing bottom
ρ	:	Mass density of water
ν	:	Kinematic viscosity
∇	:	Volumetric displacement, cubic ft.
Δ	:	Displacement, lbf
∇/A_pH	:	Mean draft-water depth ratio
W	:	Same as Δ

*Nomenclature used is ITTC Standard Symbol and that recommended in SNAME T & R Bulletin 1-23.

Introduction and Background

A significant amount of interest has been shown in the possible application of the catamaran hull as an alternative to the standard monohedron hull form. Isolated model tests have been conducted to evaluate individual designs with respect to resistance performance. However, only a limited amount of actual experimental work has been done to determine the hydrodynamic effects of hull interference.

In the 1960's the U.S. Navy limited investigations showed that one specific catamaran design had greater resistance than the equivalent mono hull forms. However, theoretical investigations and model tests have shown that a correctly designed catamaran can actually have less resistance in addition to its other operational advantages. The theoretical work of Eggers concerning wave interference effects revealed the strong possibility of reducing significantly the wave drag below that of the single hulls. This was accomplished by phase relationships in the wave pattern. Work at the National Physical Laboratory [3] has indicated, however, that the interference effects on viscous resistance, could in fact, be the opposite, resulting in an increase in resistance.

There are various methods available for predicting the performance of planing catamarans. Stevens Institute has done a significant amount of planing boat work both on the theoretical and experimental levels. Savitsky of the

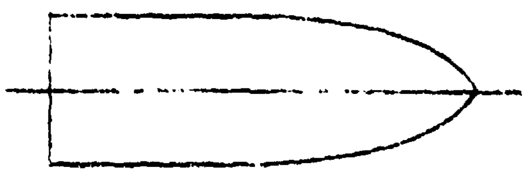
Davidson Laboratory [8] has developed a computer program for the prediction of power for prismatic planing craft. This has been modified for catamarans but does not include interference effects on drag, trim and flow characteristics on sponsons and the connecting tunnel.

Planing catamaran studies made by the U.S. Navy have indicated that the catamaran is inferior at low speeds, only performing well at high speeds, i.e. $F_\nabla = 5.0$. However, a study of this work revealed that the tunnel of the model was wetted with solid water. This in effect decreased the L_p/B_{pv} ratio of 6.2/1 (for each of the sponsons) to 2/1, increasing the wetted surface significantly.

To gain an understanding of why this leads to a hull form of poor resistance characteristics and what can be done to correct this particular aspect of catamaran hull forms, Figure 1 is provided. For illustrative purposes, a catamaran hull form can be approximated by a summation of two monohedron hull forms. This is true only as long as the tunnel of the catamaran hull form, hull form B, has a high, dry tunnel and thereby sponsons with a 6/1 L_p/B_{px} ratio. However, hull form C, with a low wetted tunnel, acts on a monohedron hull form with an L_p/B_{px} ratio of 2/1 with bottom discontinuity. This obviously leads to a hull form of poor resistance characteristics. However, as was discussed in the first paragraph, as the hull picks up speed, approximate $F_\nabla \geq 3.5$, the tunnel is no longer wetted with solid water and the hull becomes a catamaran.

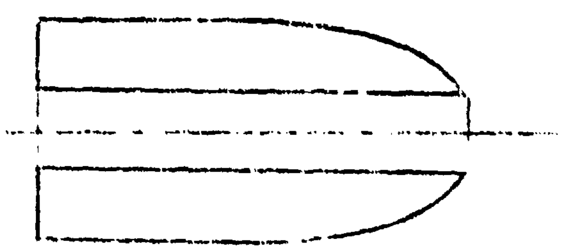
HULL FORM COMPARISON

A. MONOHEDRON HULL FORM



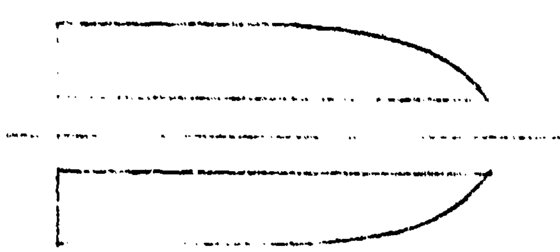
$$\frac{L_p}{B_{px}} = \frac{3}{1}$$

B. CATAMARAN HULL FORM (HIGH TUNNEL)



$$\frac{L_p}{B_{px}} = \frac{6}{1} \quad \text{(each side)}$$

C. CATAMARAN HULL FORM (LOW TUNNEL)



$$\frac{L_p}{B_{px}} = \frac{2}{1} \quad @ \; F_{\nabla}=3.5$$

$$\frac{L_p}{B_{px}} = \frac{6}{1} \quad @ \; F_{\nabla}=3.5$$

Figure 1

TABLE 1

MODEL CHARACTRISTICS

LOA	36"
Beam	6.0" (per Sponson)
Depth	5.625"
Displacement lbs. @ 70° F	8.06" (per Sponson)
Volume	.129 FT^3
LCG	9.0" Aft Of FP
Tunnel Height	
low	4.3" Off Base Line
high	5.3" Off Base Line
Sponson Spacing	0"
	6"
	12"

Test Program

Three pairs of models were constructed at the Ship Hydrodynamics Laboratory of The University of Michigan. A sketch of each is provided in figures 4, 5 and 6 for the symmetrical, assymmetrical and unsymmetrical hull forms, respectively.

The test matrix included the three variations of hull spacing from zero, six, and twelve inches. The single sponson was also towed to provide a means of comparison. Tunnel height was also varied by one inch to determine the effect of height on resistance. In all cases, LCG location and displacement were kept constant. Test conditions are listed in table 1.

An attempt was made to match test results to predicted values for resistance. The Prismatic planing boat prediction computer program as developed by the Naval Ship Engineering Center, was modified to be used on the catamaran form.

Instrumentation

A planing boat dynamometer developed at The University of Michigan was used to measure the towing force along the propeller shaft centerline. The system is set such that a servo-mechanism automatically follows the model trim so that the towing rod corresponds to the shaft line as desired.

The dynamometer employs a two arm system.

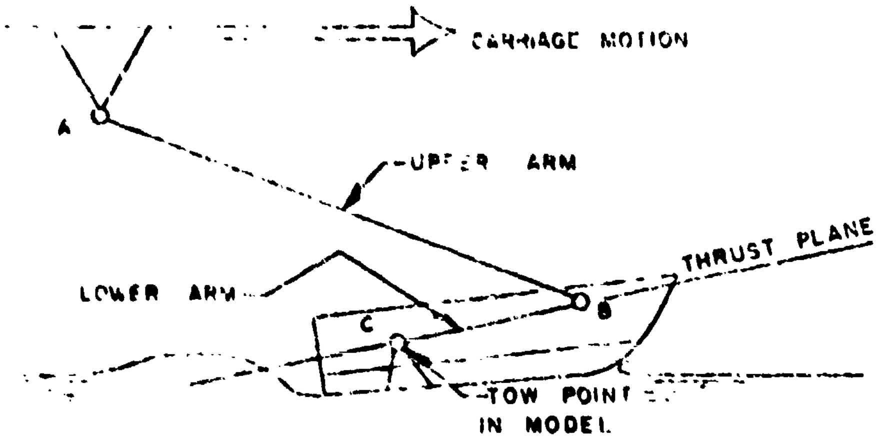
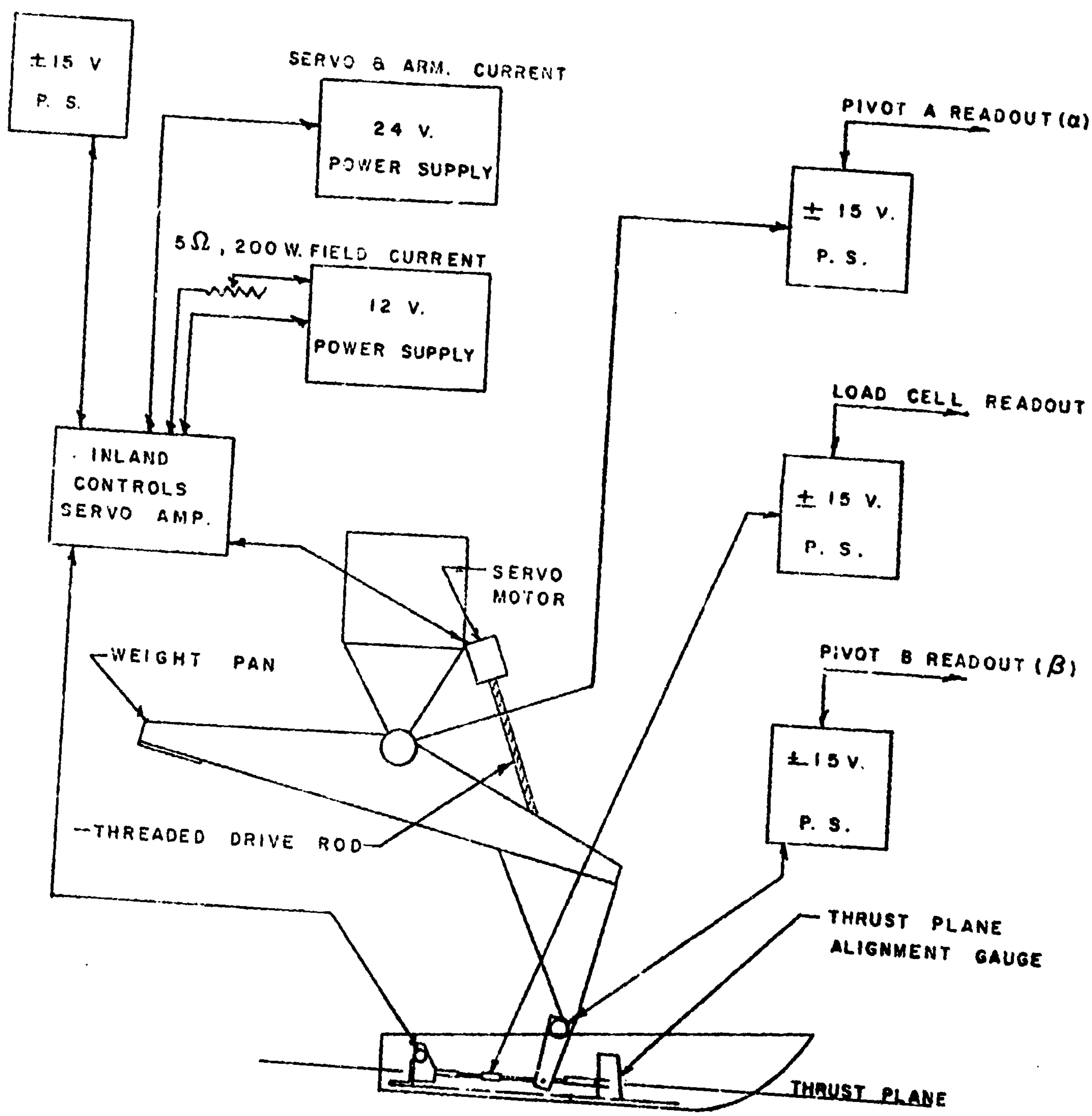


Figure 2

The model is towed so that the lower arm is in the thrust plane (so that pivots B and C are in the thrust plane). The upper arm is servo driven to retain this relationship; the feed back transducer to the servo is at the tow point C. Then, any attempted displacement of the lower arm from the thrust plane results in an angular displacement about the pivot tow point C, and the upper arm angle at pivot A is servo drive such that pivot B returns to the thrust plane.

Figure 2 illustrates a schematic diagram of the planing boat dynamometer.

Figure 3



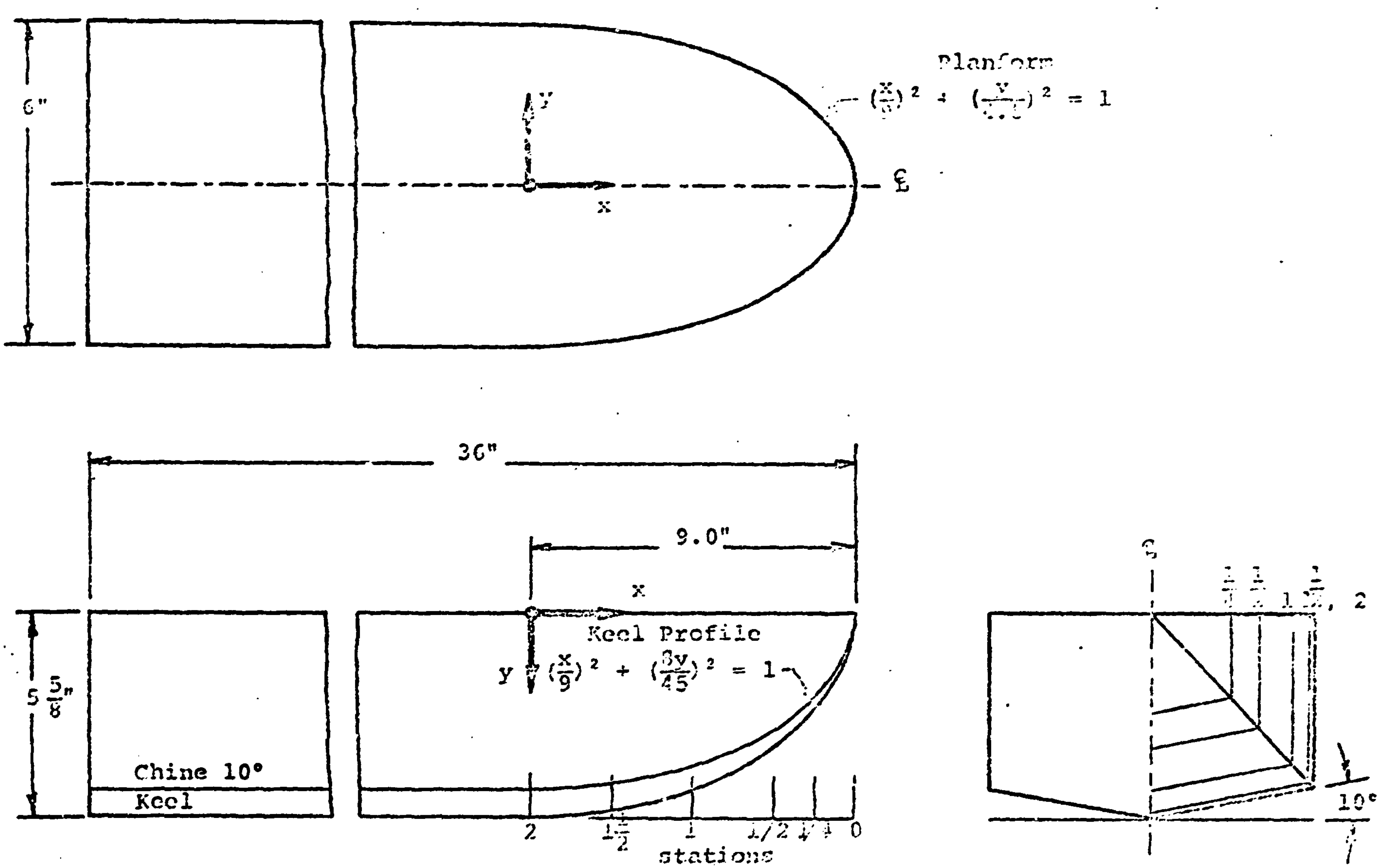


Figure 4: Symmetrical Hull Form

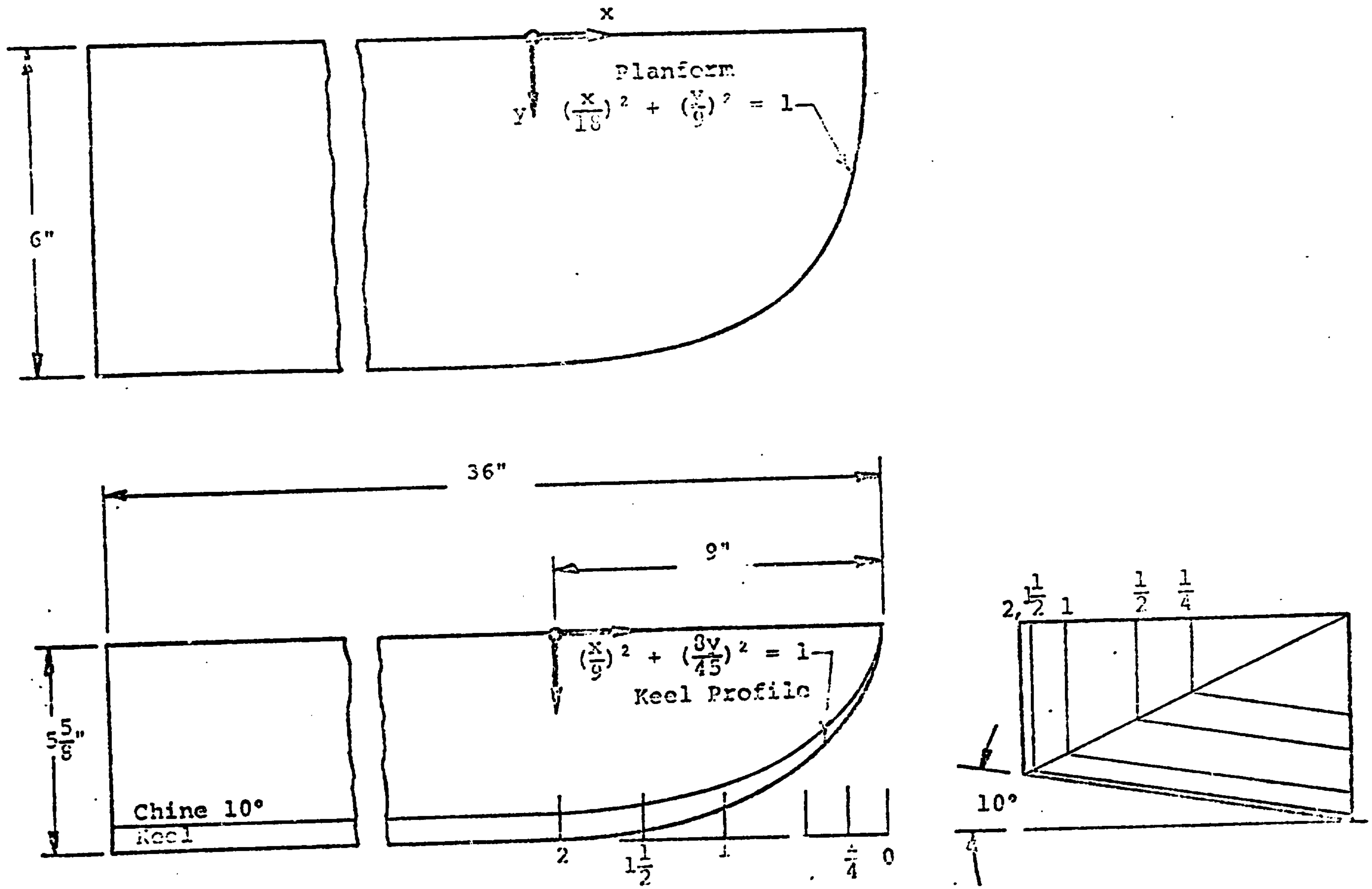


Figure 5: Assymmetrical Hull Form

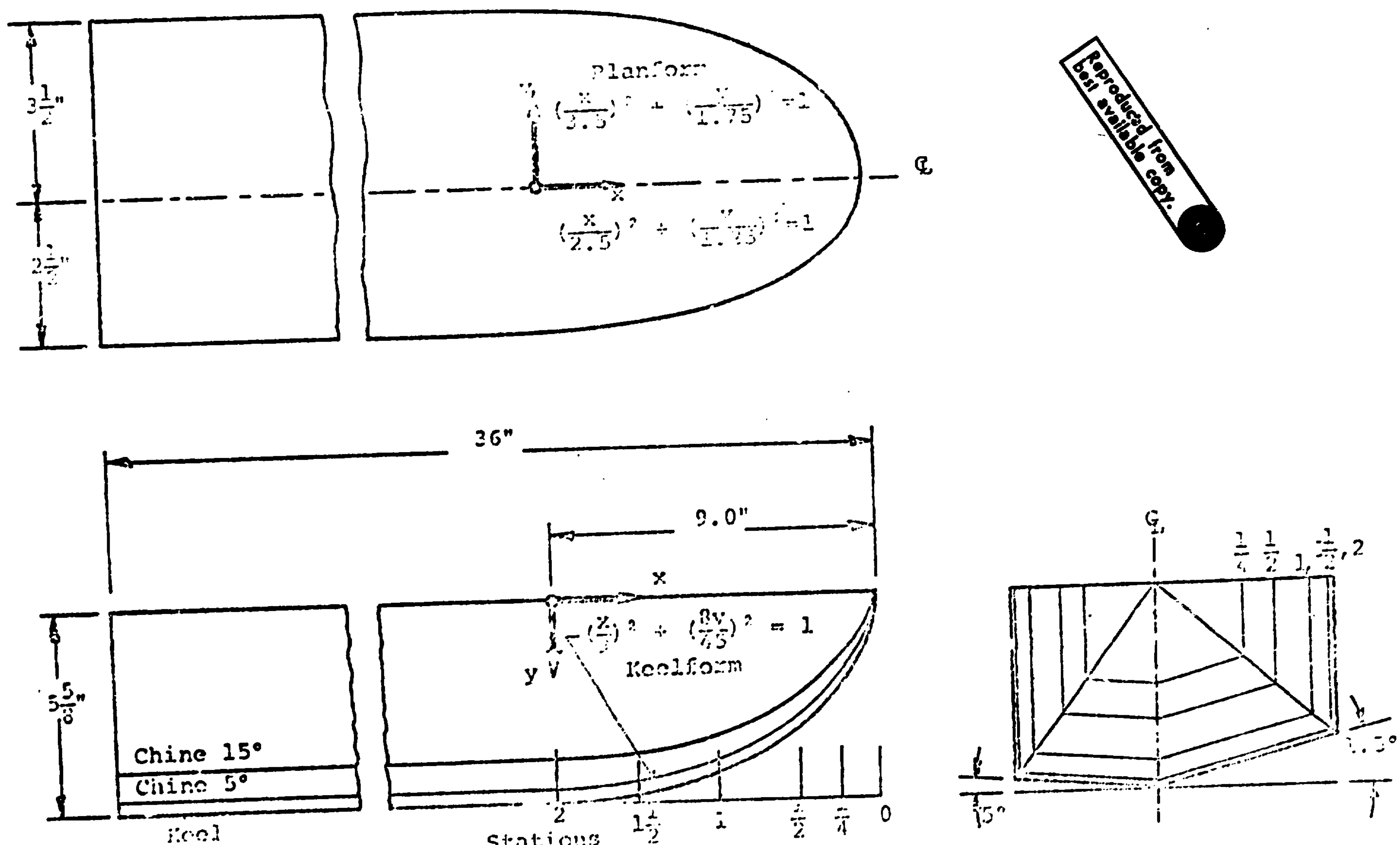


Figure 6 : Unsymmetrical Hull Form

Results and Conclusions

Test results are presented as curves of total resistance per pound of displacement versus speed-length ratio for all conditions. Figure 7 lists the results for all three of the single sponson conditions. Models were ballasted in order to acheive the "even keel" conditions for comparison to the various catamaran configurations. While the curves have indicated that these hull forms have a close comparison, the symmetrical form had a bit higher resistance especially at the lower speed-length ratio, while the assymmetric sponson was low by comparison to the other.

Correlation of resistance values for the symmetrical configuration are listed in figure 8 which the assymmetrical and unsymmetrical configurations are provided in figures 9 and 10,respectively.

While some specific trends are observed for each set of tests, the overall results appear somewhat inconclusive . In all cases, the single sponson is the best overall performer. As might be expected, however, the worst performer was the combination of sponsons with zero spacing. In general the greater the hull spacing, the lower resistance was observed. It was also observed that the tunnel had a distinct effect on the total resistance at lower speeds. However at a speed-length ratio

of about 2.5 the effect was lessened, as the tunnel wetness was reduced.

Hull form appeared within the scope of the model tests t have a distinct effect on resistance results. The unsymmetrical hulls were in general the best performers with the symmentrical hulls only slightly inferior to the assy-mmetrical sponsons.

Tunnel height, measured from the base line as 4.3"and 5.3" showed almost no variation with results and therefore are not plotted. Since maximum variations were on the order of 2%, (within the accuracy of the measurements) if it felt that the variation in tunnel height was not sufficient to completely divorce its effects.

It is felt that the results do not lend themselves to prediction methods and therefore were not incorporated within the computer program for prediction of prismatic planing craft.

Figure 7

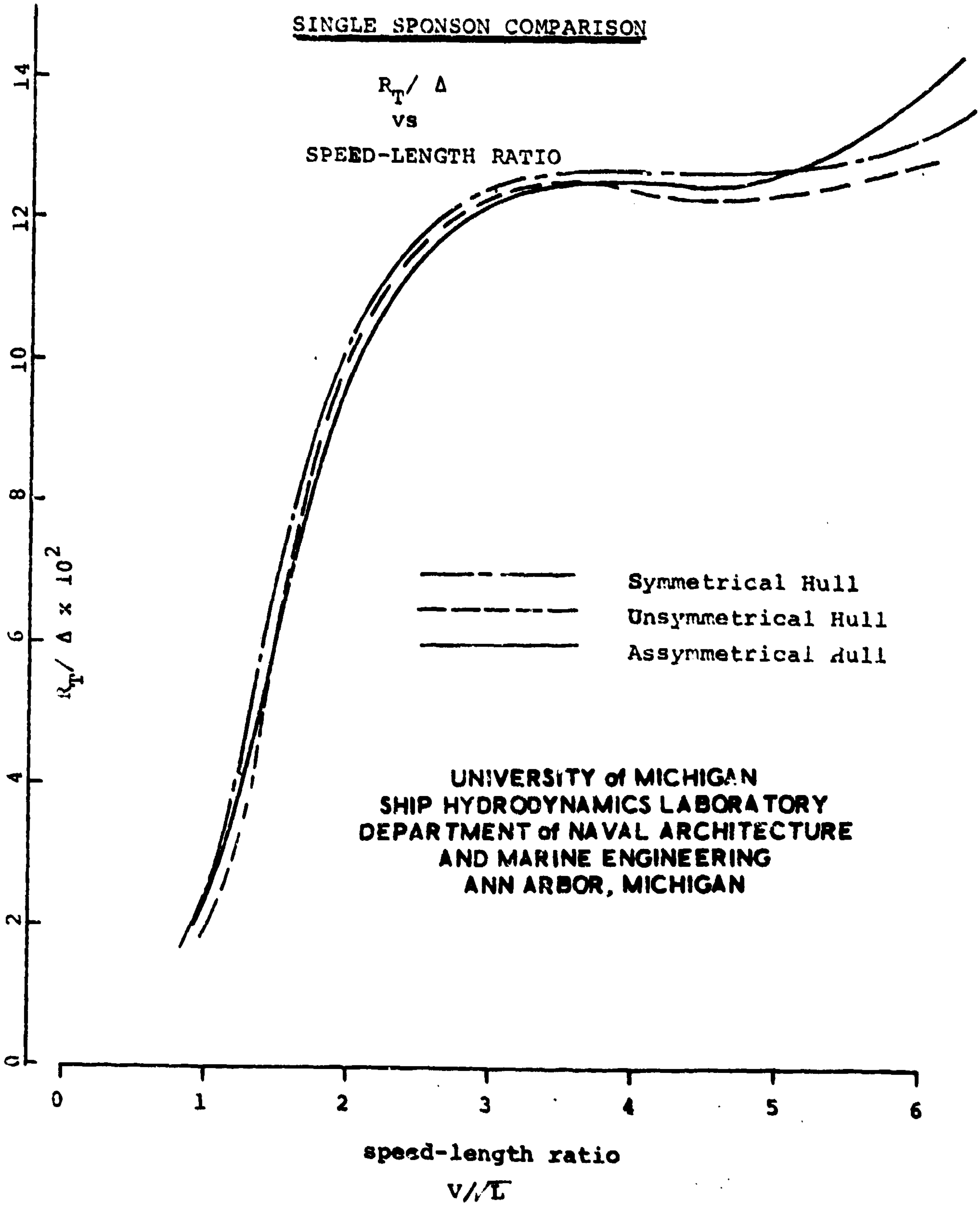

SINGLE SPONSON COMPARISON
R_T/Δ
vs
SPEED-LENGTH RATIO
$R_T/\Delta \times 10^2$
0
2
4
6
8
10
12
14
0
1
2
3
4
5
6
speed-length ratio
$V/\sqrt{L}$
Symmetrical Hull
Unsymmetrical Hull
Assymmetrical Hull
UNIVERSITY of MICHIGAN
SHIP HYDRODYNAMICS LABORATORY
DEPARTMENT of NAVAL ARCHITECTURE
AND MARINE ENGINEERING
ANN ARBOR, MICHIGAN

Figure 8

SYMMETRICAL CATAMARAN

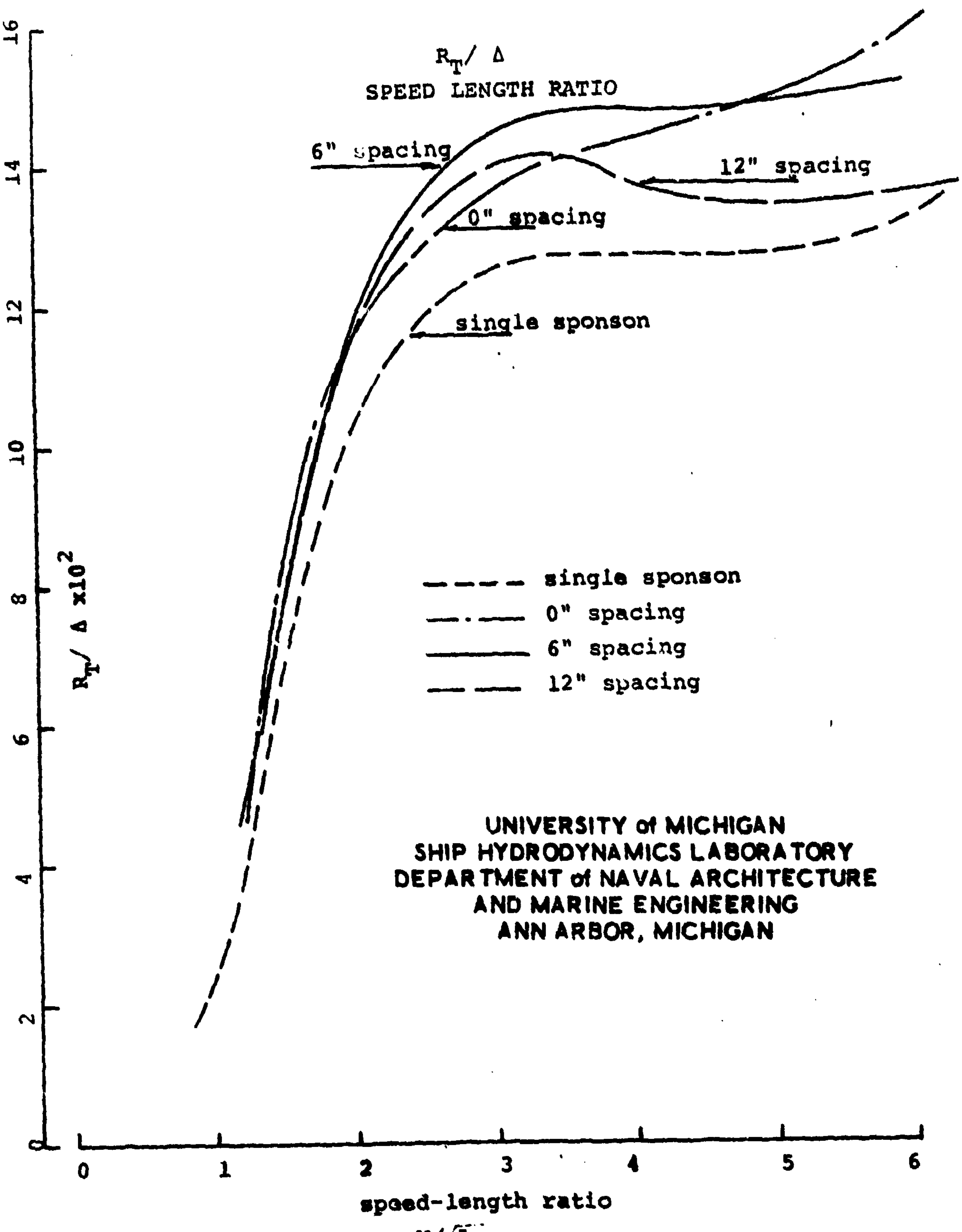


Figure 9

ASSYMMETRICAL SPONSON

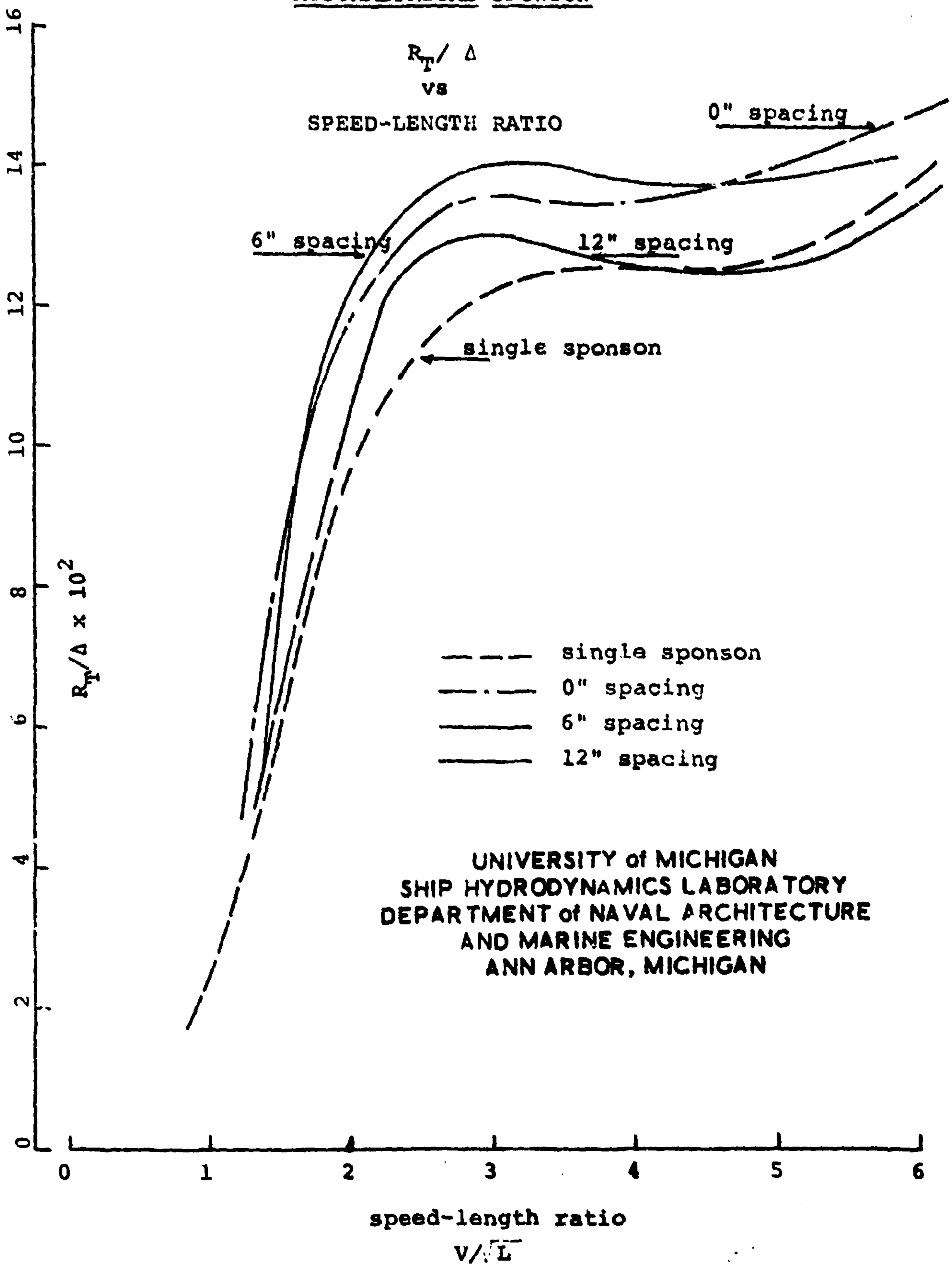
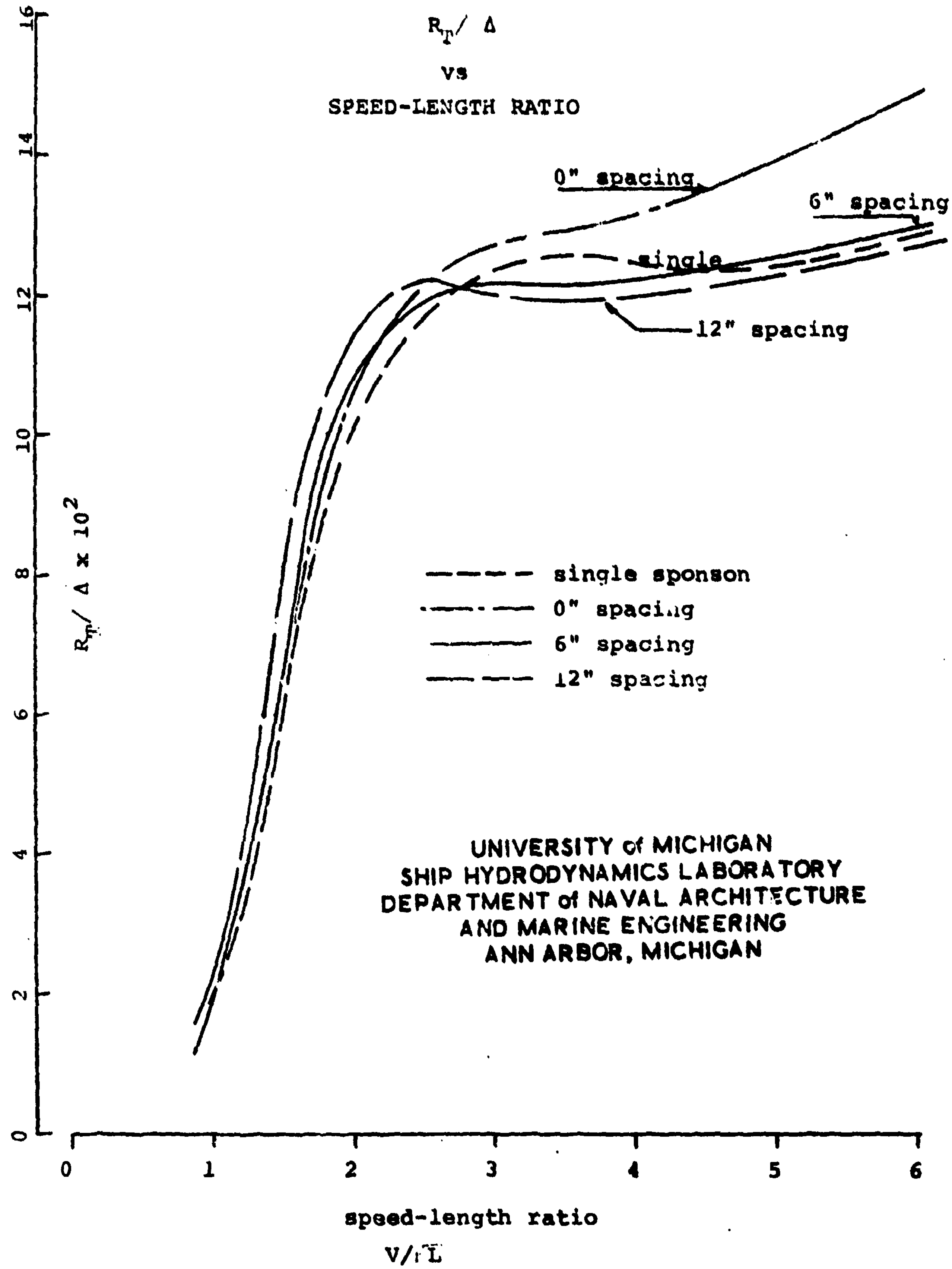
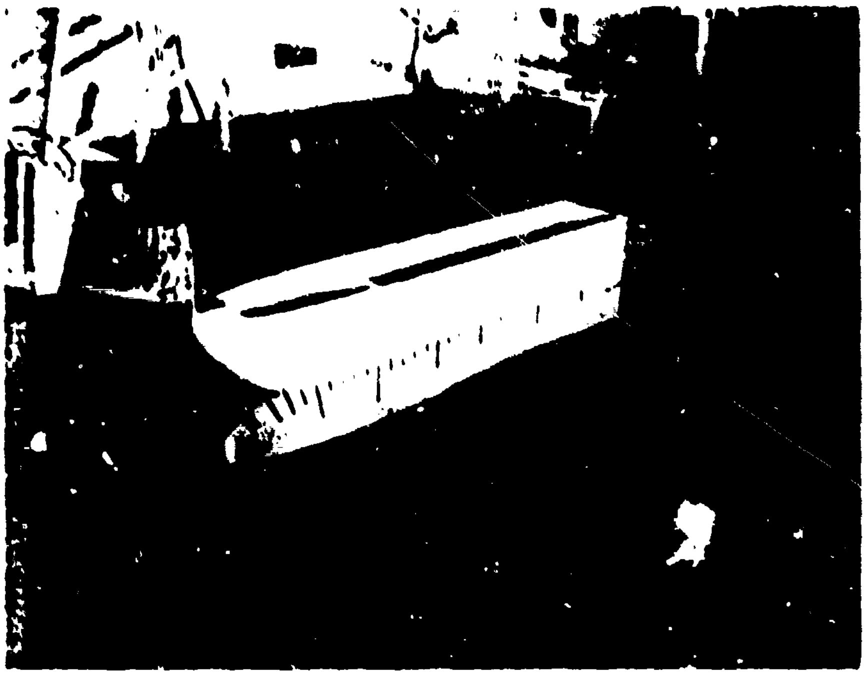


Figure 10

UNSYMMETRICAL SPONSONS
R_T/Δ
vs
SPEED-LENGTH RATIO



SINGLE SPONSON
UNSYMMETRICAL HULL FORM



$F_\nabla = 0$
Run 4.0

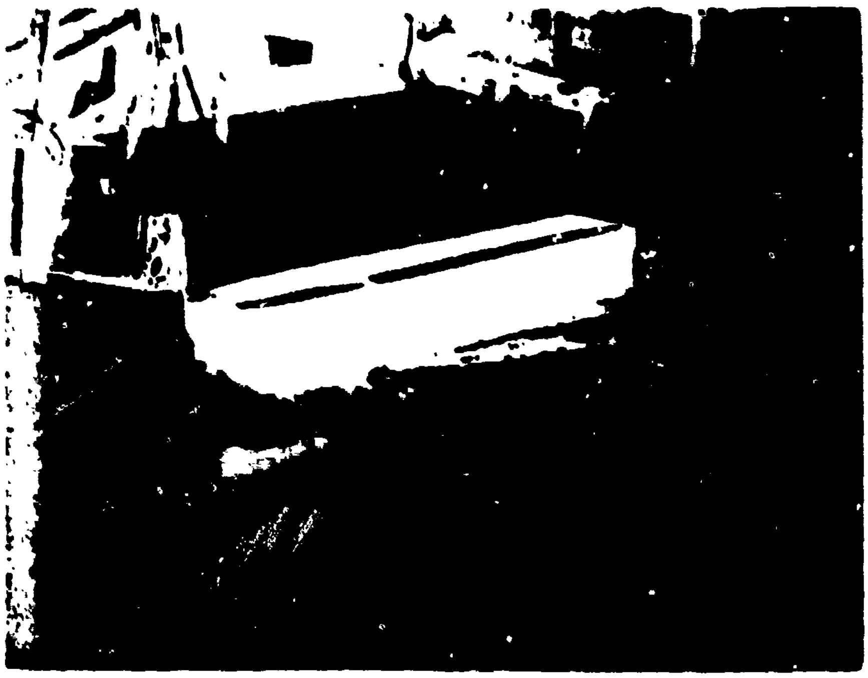
$F_\nabla = .630$
Run 4.1

SINGLE SPONSON

UNSYMMETRICAL HULL FORM

F_∇ = .981

Run 4.2

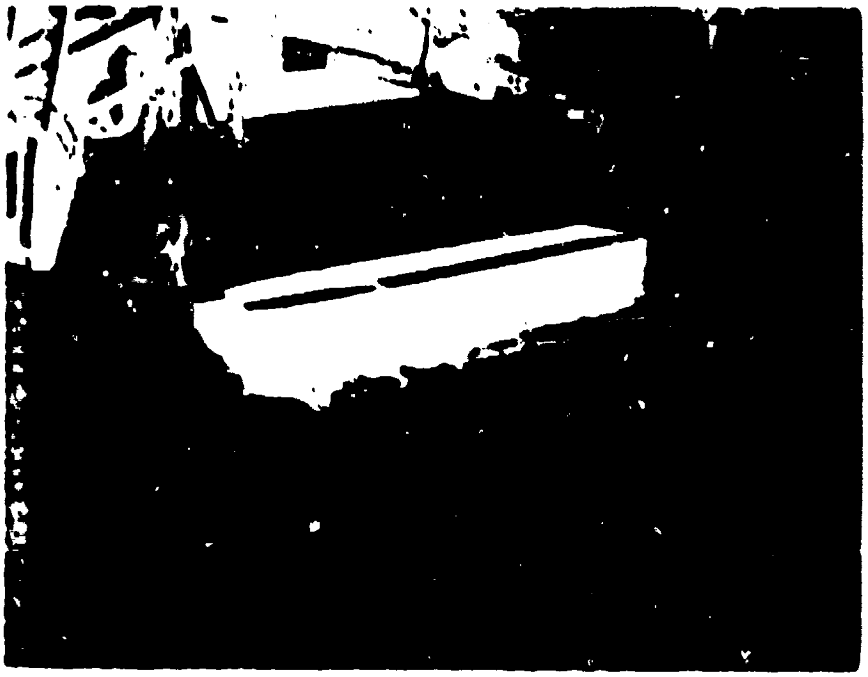


F_∇ = 1.24

Run 4.3

SINGLE SPONSON

UNSYMMETRICAL HULL FORM



F_∇ = 1.47

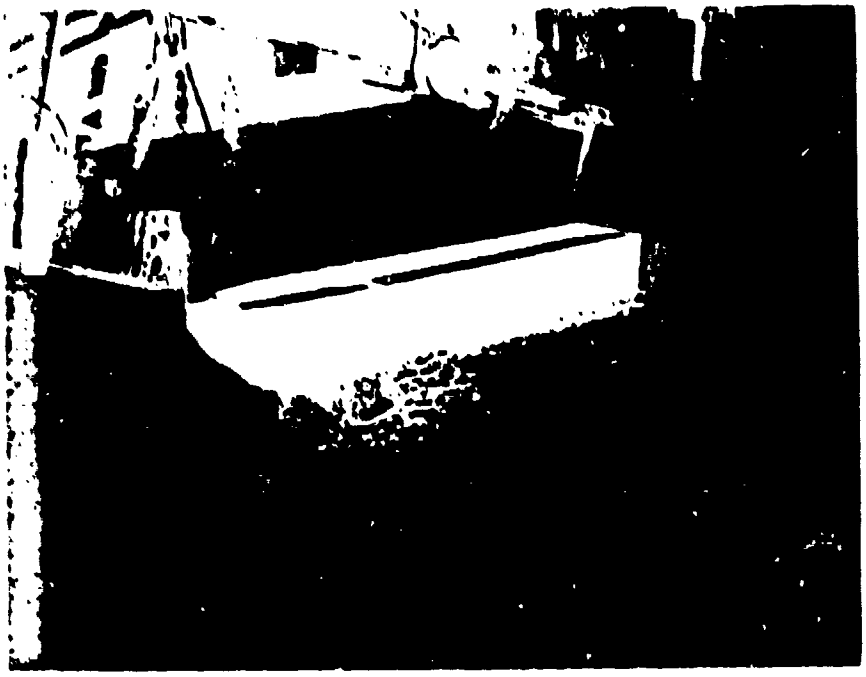
Run 4.4

F_∇ = 1.96

Run 4.6

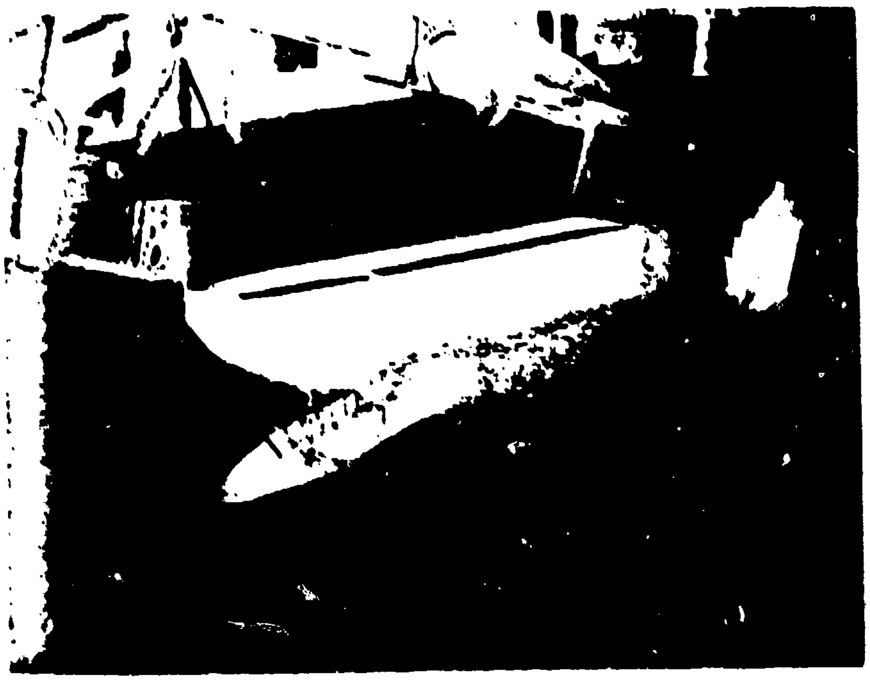
SINGLE SPONSON

UNSYMMETRICAL HULL FORM



$F_V = 2.15$

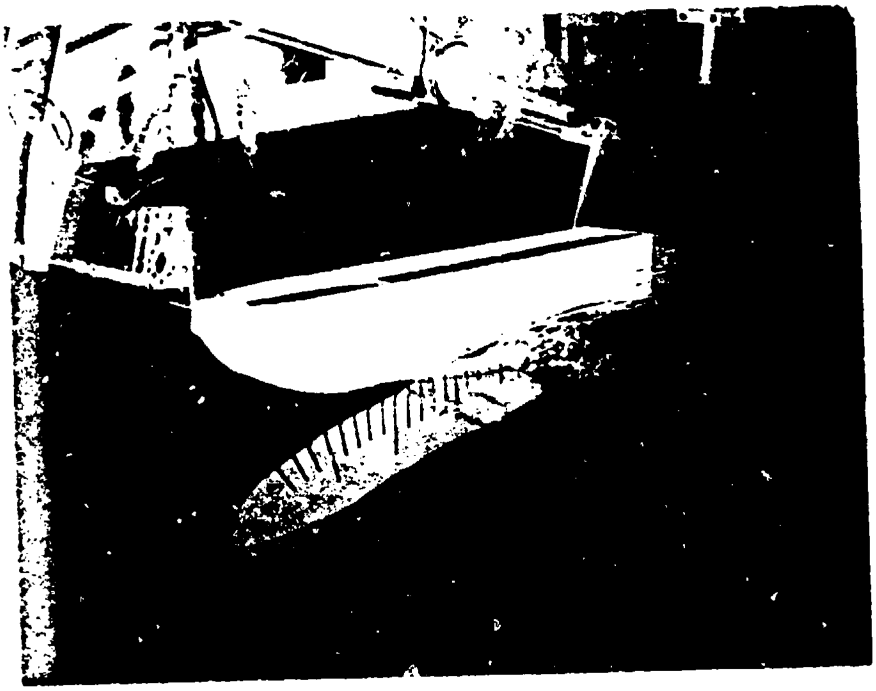
Run 4.7



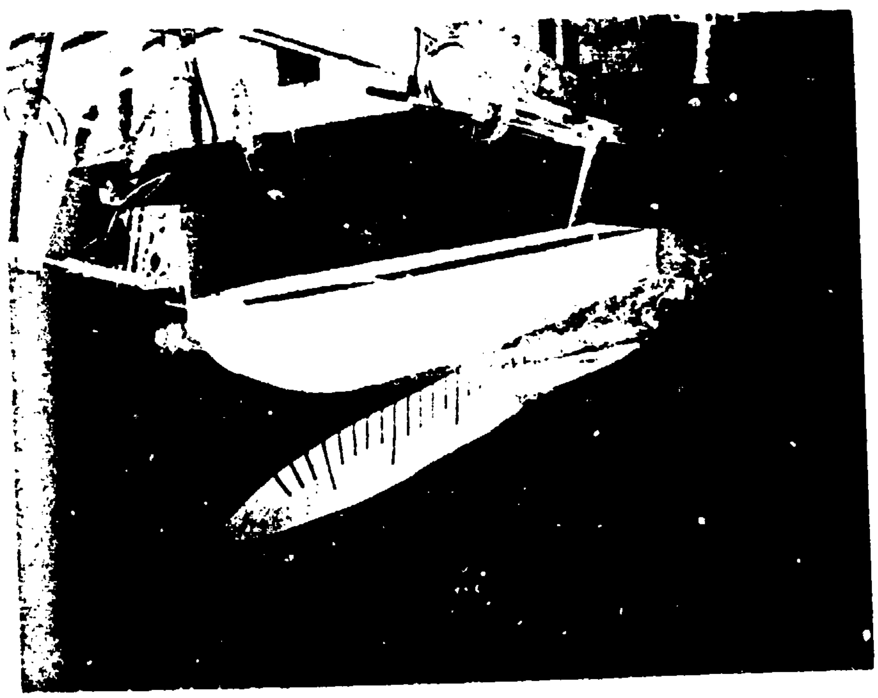
$F_V = 2.48$

Run 4.8

SINGLE SPONSON
UNSYMMETRICAL HULL FORM



$F_{\nabla} = 3.01$
Run 4.9

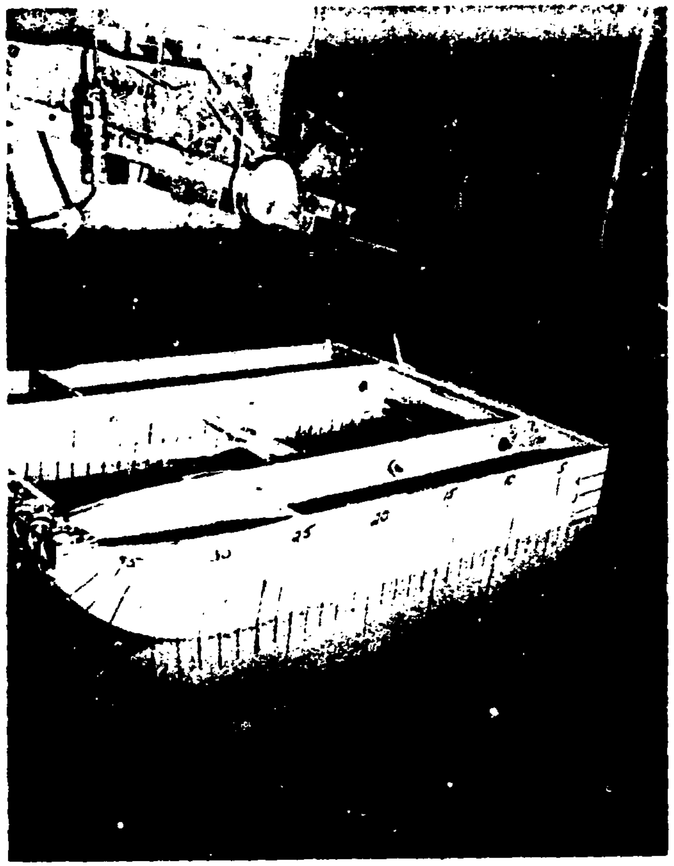


$F_{\nabla} = 3.80$
Run 4.10

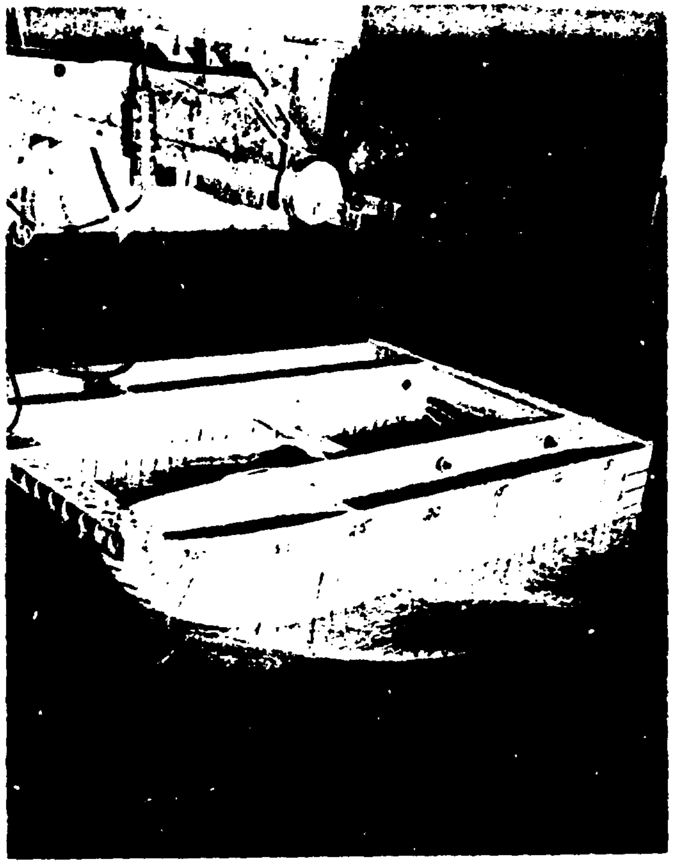
UNSYMMETRICAL HULL FORM

Spacing = 12"

Low Tunnel



$F_\nabla = 0$
Run 10.0

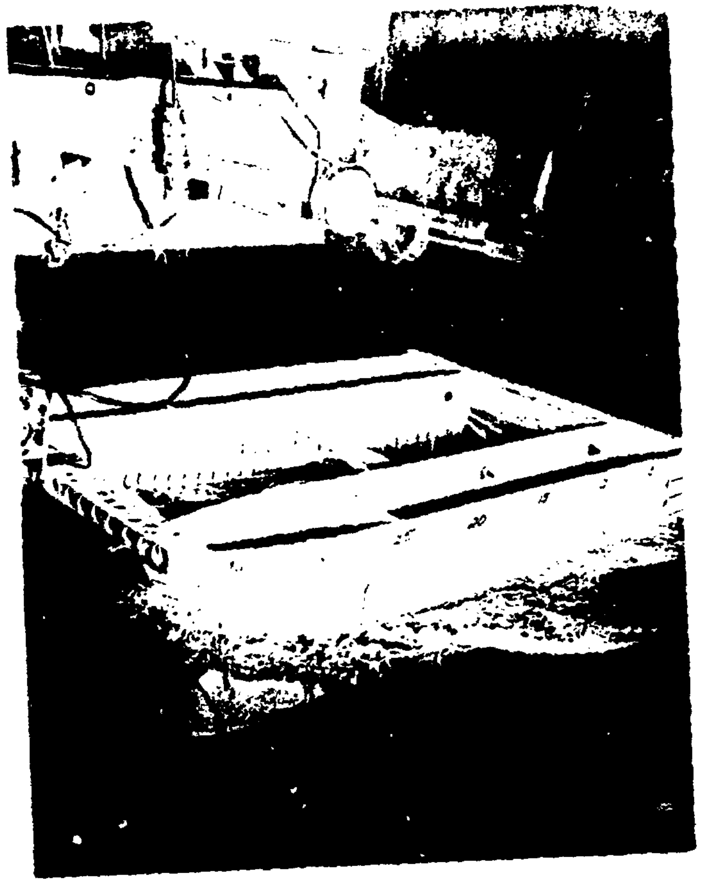


$F_\nabla = .549$
Run 10.1

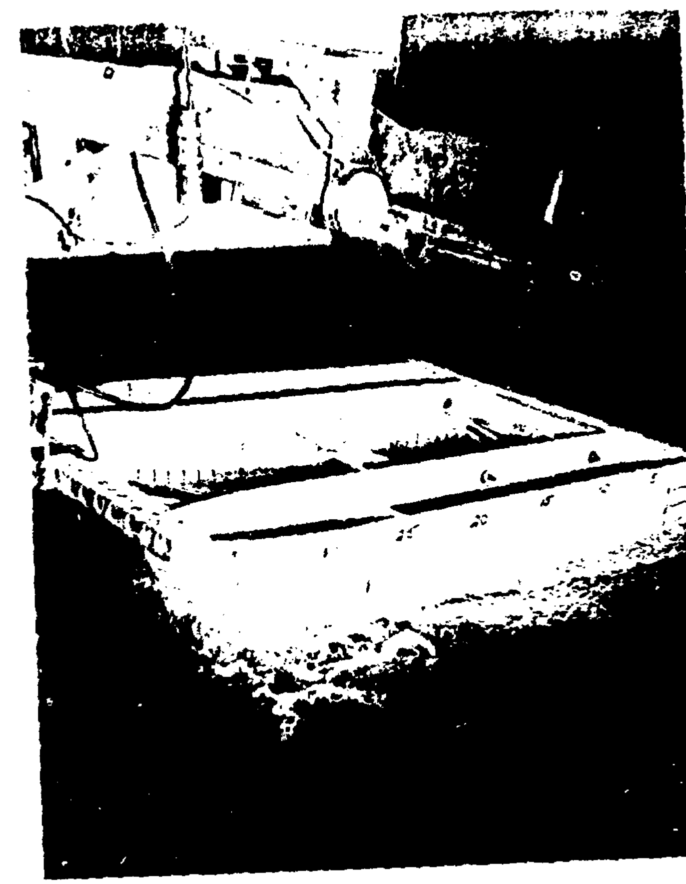
UNSYMMETRICAL HULL FORM

Spacing = 12"

Low Tunnel



F_{∇} = .929
Run 10.2

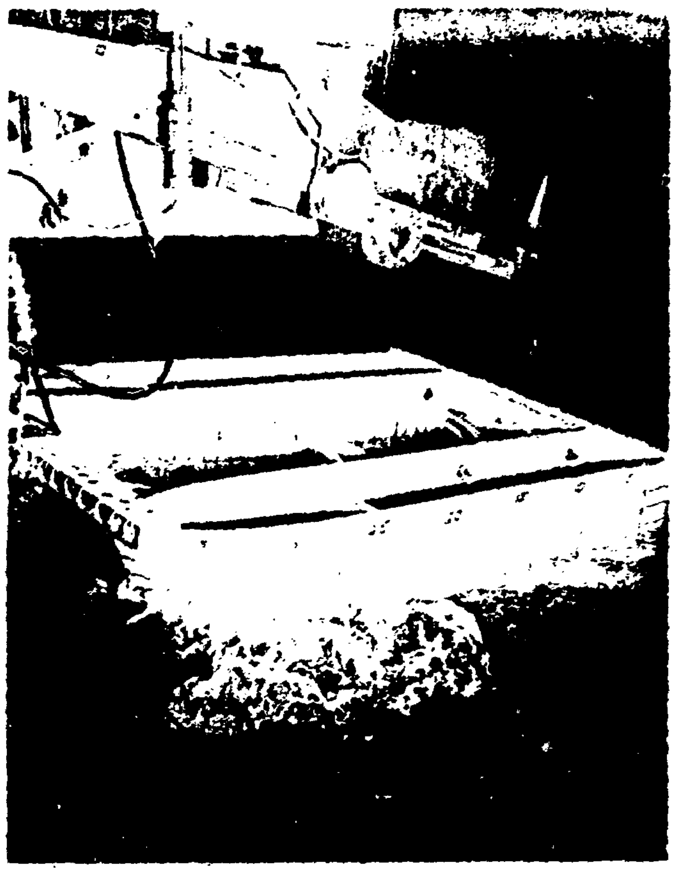


F_{∇} = 1.143
Run 10.3

UNSYMMETRICAL HULL FORM

Spacing = 12"

Low Tunnel



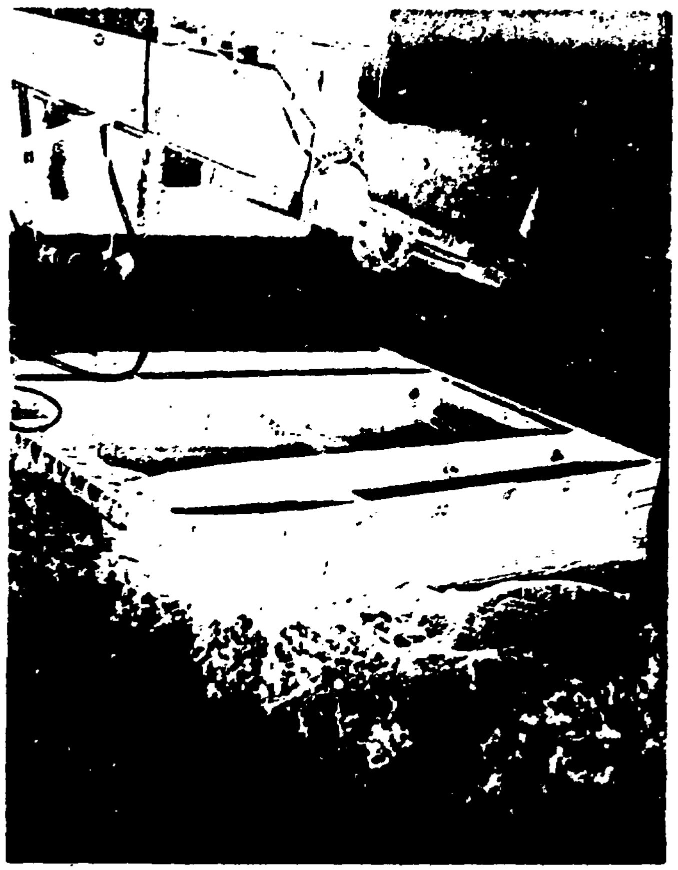
$F_\nabla = 1.30$
Run 10.4

$F_\nabla = 1.567$
Run 10.5

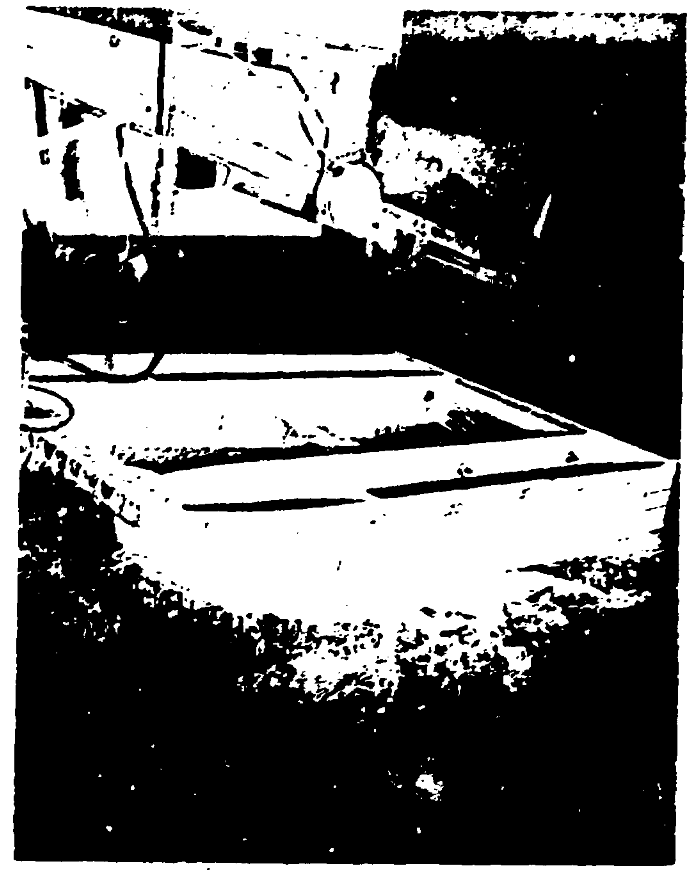
UNSYMMETRICAL HULL FORM

Spacing = 12"

Low Tunnel



F_{∇} = 1.776
Run 10.6

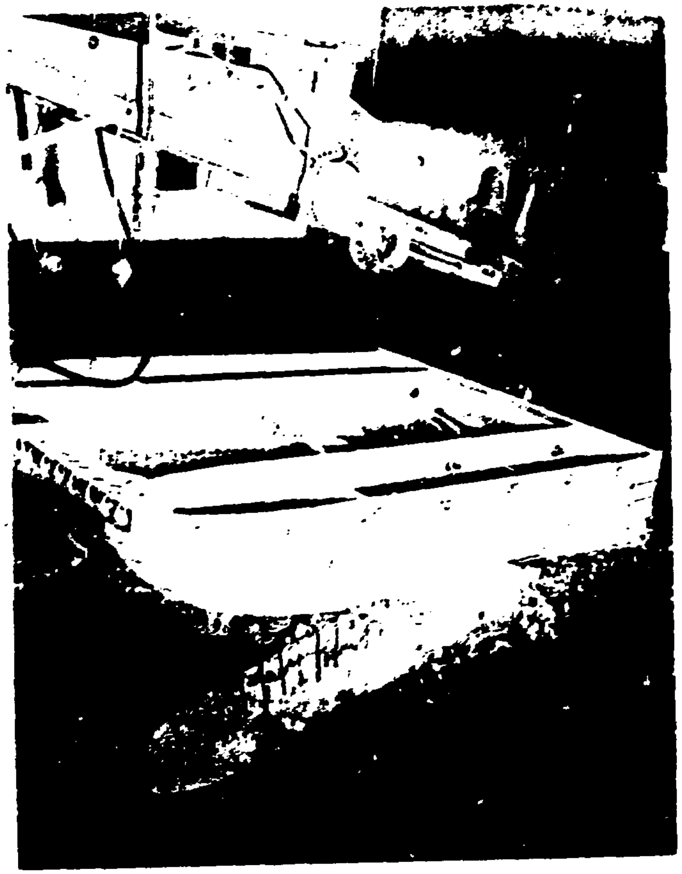


F_{∇} = 1.99
Run 10.7

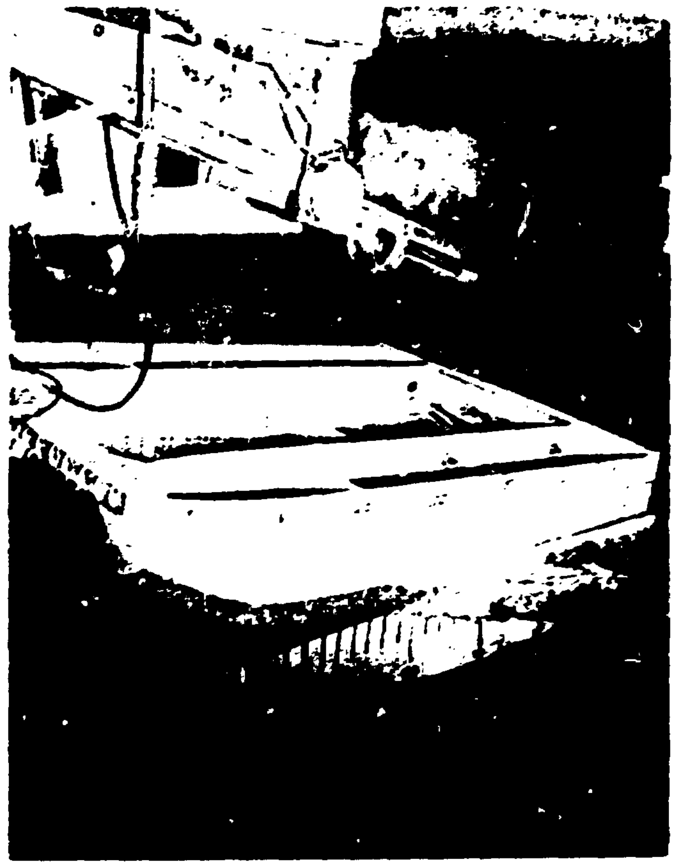
UNSYMMETRICAL HULL FORM

Spacing = 12"

Low Tunnel



$F_\nabla = 2.24$
Run 10.8



$F_\nabla = 3.24$
Run 10.11

```
.COMPILE
C     HYDRODYNAMIC DESIGN OF PRISMATIC PLANING HULLS.
C     SAVITSKY PROGRAM WD3 073 AS OF 4/4/66, IBM 1620 VERSION.
C     THIS VERSION HAS BOTH THE SKEG AND SPRAY DRAG CALCULATIONS.

      DIMENSION TITLE(20)
C     SET INITIAL VALUES FOR LATER ITERATIONS.
      QPI      = 3.1415927
      RILBW    = 3.300
      CILOB    = 0.085

    1 READ(5,110) NJOBS
      IF(NJOBS.EQ.0.) STOP
      READ(5,111)(TITLE(I),I=1,20)
      READ(5,112) VS2,DELW,DLICFI
      WRITE(6,113)(TITLE(I),I=1,20)
      VS2 = VS2 * 1.0E-5
      WRITE(6,114) VS2,DELW,DLICFI
      DO 50 JJBS = 1,NJOBS
      READ(5,112)DP1P,B1A,A3BD,CGILT,CGIVK,U1SK
      READ(5,110)NCODE,A3TAD,A3SHD,ZCGIT,DIS,XLIR,ZCGIK

C     DECIDE ON ERROR LIMIT FOR TRIM MOMENT, (XM2).
      IF( DP1P - 4000.0) 3, 3, 2
    2 DLIXM2  = 10.0
      GO TO 4
    3 DLIXM2  = 0.001

C     CALCULATE CONSTANTS OF HULL BEING RUN, RUN NUMBER AND TYPE OF RUN.
    4 A3BR     = A3BD*QPI/180.00
      A3SHR    = A3SHD*QPI/180.00
      TANB     = SIN (A3BR)/COS (A3BR)
      TANS     = SIN (A3SHR)/COS (A3SHR)
      P2K      = 0.5*DELW*(1.6889*U1SK)**2
      CILB     = DP1P/ (P2K   * B1A**2.0)
      ZCGIS    = CGIVK - B1A * TANB / 4.0
      CIV6     = (U1SK*1.6889)/(32.2*B1A)**0.5
      DK       = 0.5*QPI*(1.0-(3.0*TANB**2*COS (A3BR))/(1.7*QPI**2) -
     1   TANB*SIN (A3BR)**2/(3.3*QPI))
      IF( A3TAD) 5, 6, 5
    5 DLITAD   = 0.00
      GO TO 8
    6 DLITAD   = 3.00

C     NEWTONS METHOD OF ITERATION TO FIND CILOB, EQUATION 3.
    8 QCILOB   = CILOB-(CILOB-.0065*A3BD*CILOB**.6-CILB)/
     1   (1.0-0.0039*A3BD/CILOB**.4)
      QCHECK   = QCILOB - CILOB
      CILOB    = QCILOB
      IF(ABS (QCHECK) - .0001) 11, 11, 8

C     NEWTONS ITERATION TO FIND MEAN WETTED LENGTH-BEAM RATIO, EQUATION 2.
   11 A3TAD    = A3TAD + DLITAD
      A3TAR    = A3TAD*QPI/180.0
      TANT     = SIN (A3TAR)/COS (A3TAR)
   12 QRILBW   = RILBW-(.012* ABS(RILBW)**.5+.0055* ABS(RILBW)**2.5/CIV6*
     1*2-CILOB/A3TAD**1.1)/(.006/ ABS(RILBW)**.5+.01375* ABS(RILBW)**1.5
     2 /CIV6**2)
      QCHECK   = QRILBW -RILBW
      RILBW    = QRILBW
```

```
      IF( ABS(QCHECK) - .0001) 15, 15, 12

C     HULL FRICTION DRAG CALCULATIONS, EQUATIONS 5 AND 9.
   15 CONST    = 0.012* ABS(RILBW)**0.5*A3TAD**1.1
      U1PBM    = U1SK*1.6889*(1.0-(CONST-.0065*A3BD*CONST**.6)/( RILBW*
     1  COS (A3TAR)))**0.5
C     REYNOLDS NUMBER FOR HULL FRICTION DRAG
      XNIRE  = U1PBM*RILBW*B1A/ VS2
      DG1FRH  =    U1PBM**2* RILBW*B1A**2*(C1DS (XNIRE) + DLICF1) *
     1  DE1A*0.5/COS (A3BR)
      XL1KW    =  RILBW*B1A+B1A*TANB/(2.*QPI*TANT)
      D1KT     =  XL1KW  * SIN (A3TAR)
      DG1FRW=0.0
      ZCG1W=0.0
      DG1FRS=0.0
      IF (NCODE.EQ.0) GO TO 19
      GO TO (16, 180, 16), NCODE

C     SKEG FRICTION DRAG CALCULATION, EQUATIONS 9, 11 AND 12.
   16 IF(D1S) 18, 181, 18
C     REYNOLDS NUMBER FOR SKEG.
   18 XNIRE    = U1PBM*(XL1KW - XL1R) / VS2
      DG1FRS   =  U1PBM**2*(C1DS (XNIRE) + DLICF1)*D1S*(XL1KW -XL1R)*DE1W

  181 IF(NCODE.LT.2) GO TO 19
C     TUNNEL WALL DRAG CALCULATION, EQUATIONS 13, 14 AND 15.
  180 XNIRE = U[illegible] * XL1KW/VS2
      DG1FRW = DE[illegible]*U1PBM**2*(C1DS (XNIRE)+DLICF1)*XL1KW*D1KT / 2.0
      ZCG1W = (CG[illegible]-0.33*D1KT)/COS(A3TAD)+(CG1LT-0.33*XL1KW)*SIN(A3TAD)
C     SPRAY DRAG CALCULATION, EQUATION 10.
C     IF TRIM ANGLE IS LESS THAN 4 DEGREES, SET SPRAY DRAG = ZERO.
   19 IF(A3TAD -4.0) 13, 190, 190
   13 DG1SPH = 0.000
      GO TO 200
  190 QK1      = QK[illegible]NT/SIN (A3BR)
      QA       = (SIN (A3TAR)**2*(1.-2.0*QK) + QK**2*TANT**2*
     1  (1.0/SIN (A3BR)**2 -SIN (A3TAR)**2))**.5/(COS (A3TAR)+
     2  QK*TANT*SIN (A3TAR))
      TANP     = (QA+QK1)/(1.0-QA*QK1)
      DL1LSP   = 0.5*(TANB/(QPI*TANT) - 1.0/(2.0*TANP*COS(A3BR)))*B1A
C     REYNOLDS NUMBER FOR SPRAY FRICTION.
      XNIRE   = U1SK*1.6889*DL1LSP/VS2
      DG1SPH   = P2K*(C1DS (XNIRE) + DLICF1)*B1A*DL1LSP/COS(A3BR)


C     CHECK TO SEE IF ALL FORCES GO THROUGH THE C.G..
  200 IF (ZCG1T) 21,20,21
   20 ZCG1D   = 0.0000
      ZCG1S    = 0.000
      GO TO 22
   21 ZCG1D    = CG1VK - (B1A/4.0)*TANB
   22 ZCG1N    = CG1LT-(.75-1./(5.21*C1V6**2/ RILBW**2+2.39))*RILBW*B1A
      CONST    = ZCG1N*TANS + ZCG1T/COS (A3SHR)
      XM2      = DP1P*((COS (A3TAR)-SIN (A3TAR)*TANS)*ZCG1N - ZCG1T*
     1 SIN (A3TAR)/COS (A3SHR))+ DG1FRH*(ZCG1D - CONST) + DG1SPH*(
     2  ZCG1[illegible]CONST ) + DG1FRS*(ZCG1K - CONST )+DG1FRW*ZCG1W
      IF(  ABS(XM2) - DL1XM2) 26, 23, 23
   23 IF(DL1TAD-0.0001) 26, 24, 24
   24 IF(K12) 11, 26, 25
   25 A3TAD    = A3TAD - DL1TAD
```

```
      DELTAD   = DELTAD/4.0
      GO TO 11
C     CALCULATE REMAINING PERFORMANCE NUMBERS.
   26 DGL      = DPIP*TANT + DG1FRS + DG1FRH + DG1SPH + DG1FRW
      HPIE     = DG1*U1SK*1.6889/(550.0*COS (ABSHR))
      XL1CW    =  RILBW*B1A-B1)*TANB/(2.*QPI*TANT)
      F2POS    = (C1L8 /2.)**.5
C
C     BEGIN OUTPUT ROUTINE.
      WRITE(6,101)
      IF(ZCGIT) 28,27,28
   27 WRITE(6,102)
   28 WRITE(6,103)DPIP,ZCG10,CG1LT,ZCG1T,CGLVK,ABSHD,
     1 B1A, ABBD, U1SK, C1V6,C1LB, XM2
      WRITE(6,104)ABTAD,DGL,DG1FRH,DG1SPH,DG1FRS,DG1FRW
      WRITE(6,105)HP1E,XL1KW,XL1CW,D1KT,RILBW,F2POS
   30 CONTINUE
      GO TO 1
  101 FORMAT( 1H1,39HHYDRO. DESIGN OF PRISMATIC PLANING HULL /
     11X37H NAVSEC PROGRAM HDR 073 AS OF 6/4/66  /)
  102 FORMAT( / 6X28HALL FORCES PASS THROUGH C.G.  )
  103 FORMAT(/6HDISP = F8.1,4H LBS8X3HA = F6.2,3H FT/6H LCG =F8.1,
     14H FT 8X3HB = F6.2,3H FT/6H VCG =F8.1,4H FT 8X3HE =F6.2,
     24H DEG/6H B    =F8.1,3H FT/6HBETA =F8.1,4H DEG/6H VEL =
     3F8.1,4H KTS //5HC(V) =F8.3,4X22HMUST BE GREATER THAN 1  / 6HCL(B)=
     4 F8.3, /   6HTRIM = E13.6,6H FT-LB  )
  104 FORMAT(6H TAU =F9.3,4H DEG 21H MUST BE LESS THAN 13  //
     1   11HHULL DRAG =F12.4,4H LBS/11H FRICTION = F12.4,4H LBS /
     2 11HSPRAY DRAG= F12.4,4H LBS/ 11HSKEG DRAG = F12.4,4H LBS /
     3 17HTUNNEL WALL DRAG=F12.4,4H LBS/)
  105 FORMAT(6H EHP = F8.1,3H HP / 6HWET K= F8.1, 3H FT / 6HWET C=
     1 F8.1, 3H FT/6HDRAFT=F8.1,3H FT/6HLAMDA=F8.1,7X19HMUST BE LESS THA
     2N 4 // 22HPORPOISING STABILITY = F6.3 / )
  110 FORMAT(I5,5X,6F10.5)
  111 FORMAT(20A4)
  112 FORMAT(6F10.5)
  113 FORMAT('1',20A4)
  114 FORMAT(' VISCOSITY = ',F14.7/' DENSITY = ',F10.7/' DELTA C(F) = ',
     1F10.7)
      END

      FUNCTION C1DS(RE)
      CF = 0.075/(ALOG10(RE)-2.0)**2
      DO 10 I=1,20
      F = 0.242/SQRT(CF)-ALOG10(CF*RE)
      FP = -(0.121/SQRT(CF)+1.0)/CF
      CF = CF-F/FP
      IF(F.LE.1.0E-07) GO TO 15
   10 CONTINUE
      WRITE(6,1) RE, CF, F, FP
      STOP
   15 C1DS = CF
      RETURN
    1 FORMAT ('-****ERROR IN C1DS', 4(2X,E14.7))
      END

DATA
```

ABTAD = τ

DG1 = HULL DRAG

DG1FRH = FRICTION

DG1SPH = SPRAY DRAG

DG1FRS = SKEG DRAG

DG1FRW = TUNN. WALL

PROJECT- LIGHTSHIP WITH 11000 LB LOAD
TY = 0.1[illegible]3000E-0[illegible]
= 1.99[illegible]
( ) = 0.0340000

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